Anomalous EM signals and Changes in Electrical Resistivity at Parkfield: Collaborative Research Between the Universities of California at Berkeley and Riverside and Oregon State University

External Grant Award Number: 01HQGR0047

Gary D. Egbert; College of Oceanic and Atmospheric Sciences; Ocean Admin Bldg 104; Oregon State University; Corvallis OR, 97331-5503

Telephone: 541-737-2947; Fax: 541-737-2064; email: egbert@coas.oregonstate.edu
http://www.coas.oregonstate.edu/po/research/tide

NEHRP Element: I **Keywords:** Geophysics, Earthquake Forecasting

Investigations Undertaken:

This project is part of a collaborative observational study of possible electromagnetic (EM) earthquake precursors on the Parkfield segment of the San Andreas Fault. EM data are currently being collected by researchers at UC Berkeley (two magnetotelluric systems, at Parkfield and near Hollister) and UC Riverside (an array of long electric dipoles). The work at Oregon State University supports these efforts, with a focus on development and application of data processing methods for the EM data. Our ultimate goal is removal of ionospheric and cultural EM noise, to improve chances of detecting (and verifying the source of) possible EM signals generated inside the earth by tectonic activity. A major part of our effort during the current project period has been to develop user friendly computer codes for routine processing of data from the UCB MT sites. These codes will enable more-or-less automatic monitoring of system functionality, so technicians at UCB can be immediately alerted of any problems with the EM system. In the past years, there have been periods of weeks to months when at least some part of the monitoring system was not functioning properly. The streamlined processing codes will also allow a UCB student working part-time on the project to more easily process the backlog of data, and thereafter maintain a regular schedule for routine processing with minimal effort. Results (including daily estimates of MT inpedances, inter-station transfer functions, estimates of noise amplitudes, and summaries of frequency and time domain residual amplitudes) will be archived for statistical analysis and correlation in space and time with cluster events at Parkfield.

The processing approach being developed has three aspects. First, a MATLAB program is being developed as a user interface to download MT data from the Berkeley Seismological Laboratory, and then plot raw time series along with simple diagnostics of data quality. The program can be used to download any data in the archive, but by default gets the most recent unprocessed data. The second aspect involves a frequency domain analysis using multiple station techniques (Egbert, 1997) which makes optimal use of data from all sites and results in more stable and reliable transfer functions. These methods have proven to be very useful for better understanding of signal and noise characteristics, and for separating coherent signals of differing spatial scales. The multiple station processing has been previously implemented in Fortran; with our new processing software these programs are executed automatically, and daily or weekly output files archived. The final aspect of the software, which will be developed over the next year, will enable time domain filtering and display of residuals. This scheme, which is currently under development employs wavelet methods, as well as ideas from the frequency domain multiple station processing.

In addition to these code development activities, we have completed an initial analysis of residuals in the Parkfield MT data using the multiple station methods. Key results are summarized below. Finally, two papers reporting on closely related efforts (largely completed under previous funding) have been completed and published.

Results:

The multisite spectral approach has been applied to data from 1996-1997 (Figures 1-3). The spectrum of total signal and residual power for the Hx component of the magnetic field measurements at Parkfield was examined in three different ways by using: (a) 5 channels at the remote site for the prediction, (b) 8 channels (excluding only the local PKD magnetics), and (c) 2 PKD electric channels (Figure 1). In all cases, the predicting channels are used to estimate the uniform sources MT fields at PKD, with transfer functions computed using data from the entire 2 years. Better results are obtained for the shortest and longest periods by using more channels for the prediction. For periods from around 10-100 s, significantly better results are obtained using only the local channels. This reflects the complications in source geometry at these periods (due to cultural noise from the Bay Area Rapid Transit system (DC train), and short spatial scales associated with geomagnetic disturbances of the Pc3 type).

With residuals calculated for the two-year period, and time periods with obvious instrument failures eliminated, we computed the distribution of residuals as function of time of day (Figure 2). Because of the effects of cultural noise (and diurnal variations in the MT signal) there are significant diurnal variations in the residual distributions. Residuals are smallest between the hours of 0-4 am, making this a particularly good time to look for anomalous signals. We can assess the significance of unusually large magnetic residuals during noise-free windows, and compare these to local earthquake catalogs (Figure 3). Comparisons to date have revealed no clear associations, but there have been very few earthquakes of significant magnitude in the time period studied. Our experiment is now well calibrated so that when the next major Parkfield event occurs we will be in a very good position to detect any sort of unusual EM emissions that might occur. There are already some instances when residuals are unusually large (Figure 3); we are examining these carefully for instrument problems first and then for possible correlation with other possible geophysical anomalies.

The MT stations at PKD and SAO can also be used to monitor resistivity changes prior to earthquakes. Seasonal changes caused by precipitation would presumably be shallow and affect primarily the shorter periods, while deeper changes would be seen also at longer periods. The amplitude of the MT impedance may fluctuate at all periods in response to shallow changes (the so-called "static" shift problem), but the phase of the response is set by more regional structure at longer periods. Thus, variations in phase should be a sensitive indicator of resistivity variations at seismogenic depths (~10 km).

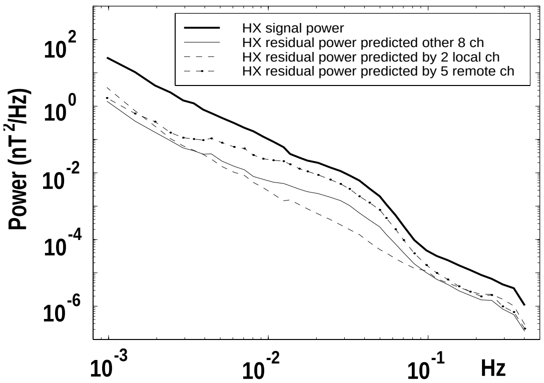

Figure 1: Power spectra for total measured signal and residuals, for Hx at PKD1. Spectra are computed as the median power of all half hour time windows in 1996-97. Residuals are computed using a uniform source transfer function, with the uniform source fields estimated three different ways: (a) using the local electric fields at PKD1 (dashed line)(b) the 5 remote channels at SAO (dash-dot line) and (c) with all other 8 channels (5 at SAO + 3 at PKD). At the shortest and longest periods using additional channels leads to better noise removal. However,for frequencies of .003 - .1 hz complications in source fields due to BART and Pc3s make limit the effectiveness of predictions based on the remote site only.

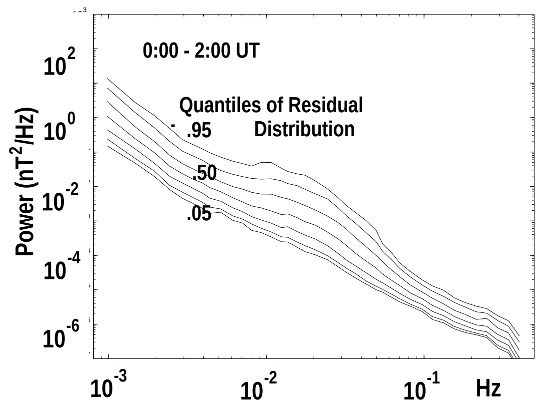

Figure 2: Quantiles of the statistical distribution of residual power for Hx at PKD1. Residuals were predicted using all 8 other channels, and residual power was computed in half hour time windows. The quantiles plotted are from bottom 0.5, 0.10, 0.25, 0.5, 0.75, 0.9, 0.95. For example the 0.95 quantile gives the power level that 95% of all time windows fall below. Quantiles of residual power distribution were computed as a function of time of day, with two hour resolution. There are significant diurnal variations of residual distribution, with large amplitude events least likely in the late night hours, as for the example plotted here.

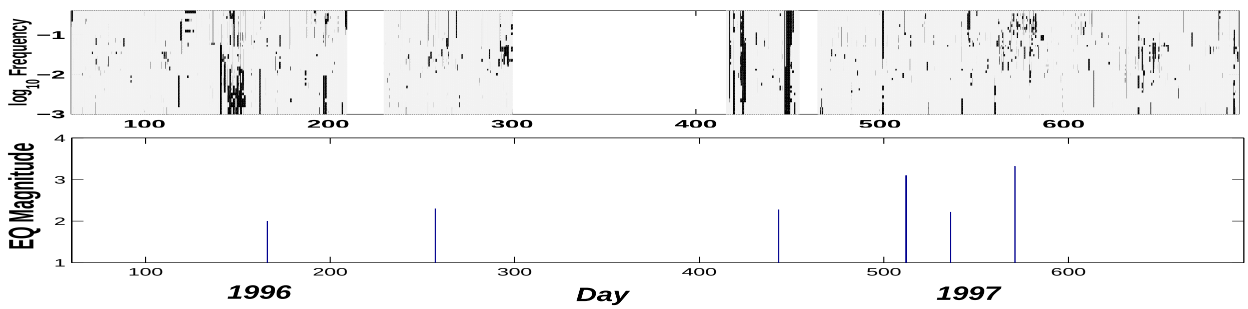

Figure 3: Comparison of instances of unusually large residuals in Hx atPKD1 with local seismicity. In the upper panel times (1/2 hour windows), and frequencies where residual power exceeded the 0.95 quantile for the appropriate frequency and time of day. Here we restrict ourselves to late night (0:00-4:00 am) time windows, and use the other 8 components for residual computation. In the lower panel all earthquakes in the NCSN catalogue with local (MLm) magnitude greater than 2, shallower than 10 km, and within 10 km of PKD1 are plotted. There is no obvious correlation of large residuals and earthquakes evident. Some of the larger residual events probably reflect some sort of equipment malfunction, but we have not been able to verify the exact cause yet.

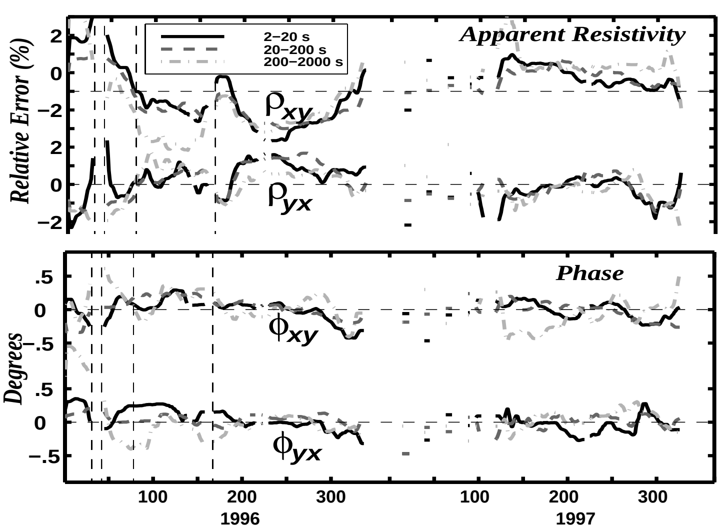

Figure 4: Deviations of MT apparent resistivity and phase from long term averages at PKD1, averaged over wide frequency bands and 11 day time windows for 1996-1997. The vertical dashed lines in the first half of 1996 correspond to changes in equipment, and appear to be associated with the largest variations. After this time instrument configurations were stable. Gaps denote times of instrument failure. Variations of phase and relative variations of resistivity are plotted on a consistent scale, so that random noise should produce comparable variations. In fact, there appears to be significantly more variation in apparent resistivity. This variability is anti-correlated between modes, and largely independent of frequency. These features suggest time varying near surface distortion. Seasonal effects are not clear in these results, but longer monitoring would be desirable to verify this.

MT impedances computed daily for 1996-1997 have been generally stable (Eisel and Egbert, 2001). Typical deviations of estimates based on a single day of data differed from the long term average transfer function by 2-3% for T<300s and increasing to about 10% for T=2000s. Variations between contiguous days were nearly random, so significantly smaller variability can be obtained by longer averaging times. There is some evidence from this analysis for a slow variation of 1% in impedance amplitude when an 11-day average is applied (Figure 4). The variations are nearly frequency independent, and appear anti-correlated between the x-y and y-x modes. Long-term phase variations are smaller (note that amplitude and phase are plotted in Figure 4 with consistent scales). These features are suggestive of temporal variations in near-surface static distortion. Although it is difficult to make a definitive statement on the basis of the two years of data analyzed so far, there does not appear to be any seasonal component to these variations, as might be expected if they were due to near surface hydrology.

Non-Technical Summary:

This project is part of a search for possible electromagnetic (EM) earthquake precursors on the San Andreas Fault near Parkfield California. There have been a number of reports of anomalous EM signals preceding large earthquakes, and it has been suggested that such signals could be useful predictors of seismic activity. However most observations of EM precursors have been fortuitous, and difficult to verify. This project aims at more systematic monitoring, so that any possible precursors in the Parkfield area would be observed under more controlled circumstances. The work at Oregon State University supports field efforts, with a focus on development and application of data processing methods. Our goal is to remove ionospheric and cultural EM noise, thus improving chances of detecting and better understanding the nature of any EM signals associated with earthquakes.

Reports Published:

Egbert G.D., On the generation of ULF magnetic variations by Conductivity Fluctuations in a Fault Zone, *Pure Appl. Geophys*., in press, 2001.

Eisel, M. and Egbert, G.D., On the stability of magnetotelluric transfer function estimates and the reliability of their variances, *Geophys. Jour. Int*., **144**, 65-82, 2001.